10/563011
IAP15 Rec'd PCT/PTO 30 DEC 2005

SMALL INTERFERING RNA SPECIFIC TO SUBUNITS α, α' AND β OF THE PROTEIN KINASE CK2 AND THE APPLICATIONS OF THE SAME

The invention relates to small interfering RNA (or silencing inducing RNA), hereinafter referred to as siRNA, specific for the α, α' and β subunits of the CK2 (or caseine kinase 2) protein kinase and to the applications thereof, in particular for the treatment of cancers.

The CK2 (or caseine kinase 2) protein is a pleiotropic or ubiquitous serine/threonine kinase that is very conserved in eukaryotics; this holoenzyme is composed of two catalytic subunits α and α' and two identical regulatory subunits β, associated in the form of $\alpha\alpha'\beta_2$, $\alpha'_2\beta_2$ or $\alpha_2\beta_2$ heterotetramers.

This protein plays an essential role in the control of many physiopathological processes; it is essential to embryonic development and to terminal differentiation, and to the control of progression of the cell cycle and of cell survival, and its expression is deregulated in many cancers including tumors of viral origin, where it contributes to the blocking of apoptosis (Buchou et al., Mol. Cell. Biol., 2003, 23, 908-915; Ahmed et al., Trends in Cell Biology, 2002, 12, 226-230).

Because of its essential role in many physiological processes and because of the importance of the pathologies associated with the dysfunction therefor, the CK2 protein represents a new pharmacological target for the development of medicinal products, in particular anticancer and antiviral agents.

However, given that the knocking-out of the CK2 subunit genes is lethal in knock-out transgenic mice and incompatible with cell viability (Buchou et al.,

mentioned above), the development of such molecules has remained very limited in the absence of any *in vivo* or *in vitro* model for the functional analysis of the role of the CK2 subunits.

In fact, the few molecules capable of inhibiting CK2 that have been described have the drawback of being either not very specific or not very active, i.e.:

- small molecules which are analogs of ATP, capable of specifically inhibiting the catalytic α and α′ subunits; as an ATP analog, mention may be made of TBB (Sarno et al., FEBS lett., 2001, 496, 44-48), which is a derivative of DRB for increasing its specificity for the alpha subunit of CK2. However, these kinase substrate (ATP) analogs can inhibit the activity of other known or unknown proteins, using cellular ATP. Since the specificity of such products, and in particular of TBB, is uncertain, their use is excluded *in vivo*,

- antisense oligonucleotides directed against the subunits of CK2 (American application US 2002/147163 and American patent US 6 455 307 in the name of Isis Pharmaceuticals Inc; Ulloa et al., EMBO, 1993, 12, 1633-1640; Faust et al., Head & Neck, 2000, 22, 341-346); the inhibition of CK2 activity, demonstrated only *in vitro* is partial and transient and requires very high doses of antisense oligonucleotides (several tens to several hundreds μg/ml depending on the sensitivity of the cells).

It emerges from the above that no molecules capable of specifically inhibiting the CK2 protein kinase in an effective manner exists. In addition, no *in vitro* or *in vivo* model exists for a functional analysis of each of the CK2 subunits, useful for screening for molecules capable of modulating the activity of the CK2 protein kinase.

It has been shown that double-stranded RNA fragments complementary to an mRNA are capable, where they are introduced into eukaryotic cells, of strongly inhibiting the expression of the corresponding gene by destroying this mRNA. The phenomenon, called RNA interference (for a review see: Biofutur, 2002, volume 228, pages 52-61; Voorhoeve et al., TIBS, 2003, 21, 2-4), has been demonstrated and particularly well studied in plants and invertebrates (*Caenorhabditis elegans*, drosophila) and it is reasonable to assume that a similar mechanism exists in higher animals, since RNA interference has also been observed in human cells in culture. However, it has been shown that, in invertebrates, the phenomenon is even capable of spreading to the entire organism and of persisting after cell division, something which has not been observed in higher animals.

Small double-stranded RNA fragments, 21 to 25 nucleotides long, are the real initiators of the inhibition. These siRNAs can penetrate directly into plant cells and probably also into invertebrate cells. In drosophila, it has been shown that siRNAs integrate into molecular complexes called RISCs (RNA-induced silencing complexes). By means of a helicase and of ATP as an energy source, these complexes expose the strands of the siRNA. If the genetic sequence of the siRNA corresponds to a fragment of a gene that is naturally expressed in the cell, the interfering RNA exposed by the RISC complex will encounter a messenger RNA carrying a sequence that is exactly complementary and the two molecules will associate. The presence of the siRNA strand causes enzymes to become involved which will cleave the messenger RNA at the site where it is bound to the siRNA. The two parts of the cleaved messenger RNA, deprived of one of their usual endings, are identified as incomplete and destroyed by the cell. The messenger RNA targeted can no longer play its role

and control the synthesis of a protein. This is what explains the extremely specific nature of RNA interference (R. Agami, Current Opinion in Chemical Biology, 2002, 6, 829-834; there is only a reaction if an exact homolog of the sequence of about twenty nucleotides of the siRNA exists on a messenger RNA. The probability of a segment of DNA, taken randomly, corresponding to a given siRNA is of the order of 1/4 to the power 21 (21 nucleotides which can each have 4 "values"), i.e. one chance in more than 4 billion.

This phenomenon of specific inhibition of gene expression opens up advantageous perspectives in the field of functional genomics and of pharmaceutical research, respectively, for rapidly identifying the function of new genes, and for rapidly selecting target genes and candidate medicinal products.

Thus, siRNAs specific for cDNAs encoding viral or cellular proteins and capable of inhibiting the production of the corresponding proteins have been described (p24 of HIV, gD of HSV, IL-12; PCT international application WO 00/63364).

However, no siRNA capable of specifically inhibiting the expression of the subunits of the CK2 protein kinase has been described.

Surprisingly, the inventors have isolated siRNAs specific for the transcripts of the α, α′ and β subunits of CK2 that are capable of selectively blocking the expression of the α subunit, of the α′ subunit or of the β subunit of the CK2 protein kinase in cells, effectively, specifically and in a long-lasting manner. Such siRNAs which exhibit a prolonged inhibitory effect, of the order of 72 hours, at low concentrations (of the order of 20 nM, *in vitro*), are useful as medicinal products for the treatment of cancers. Specifically, a concentration of 20 nM of

siRNA inhibits more than 80% of the expression of the CK2 protein kinase subunits (detected by Western blotting) and of the corresponding mRNAs (quantification by RT-PCR on a light-cycler) after 48 h in human cells (MCF7, HeLa or 3T3 fibroblasts).

In addition, these RNAs which specifically inhibit the expression of the α, α′ or β subunit of the CK2 protein kinase also represents tools for the functional analysis of the respective role of each CK2 unit and the screening for molecules capable of modulating (activating or inhibiting) the activity of one or more of these CK2 subunits.

A subject of the present invention is thus a double-stranded oligonucleotide made up of two strands of 19 to 23 nucleotides, each strand consisting, from 5′ to 3′, of a sequence of 17 to 21 ribonucleotides and two deoxyribo- or ribonucleotides, the 17 to 21 ribonucleotide RNA sequences of said strands being complementary and the two nucleotides of the 3′ ends being protruding, characterized in that the RNA sequence of the sense strand or positive strand is that of a fragment of a transcript of an α, α′ or β subunit of a CK2 protein kinase, selected from the group consisting of:

a) a fragment corresponding to an oligonucleotide which inhibits more than 80% of the expression of the corresponding subunit, in cell culture, at a concentration of between 1 and 200 nM, preferably less than 20 nM,

b) a fragment of a transcript of an α subunit included between positions 18-74, 259-279, 565-585, 644-664, 720-750, 808-831 and 863-885, from the ATG codon, with reference to the cDNA sequence of the CK2 α subunit of mouse No. NM_007787 or human No. NM_001895,

c) a fragment of a transcript of an α' subunit included between positions 49-69, 132-142, 306-326, 367-387, 427-447, 451-471, 595-615, 735-755, 827-847, 868-888, 949-969 and 988-1008, from the ATG codon, with reference to the cDNA sequence of the CK2 α' subunit of mouse NM_009974 or human No. NM_001896,

d) a fragment of a transcript of a β subunit included between positions 80-100, 116-127, 164-208, 369-389, 400-420, 527-591 and 613-643, from the ATG codon, with reference to the cDNA sequence of the CK2 β subunit of human No. NM_001320 or of mouse No. NP_034105, and

e) a fragment of 17 to 21 nucleotides exhibiting at least 80% identity with the fragments defined in a), b), c) and d).

The double-stranded oligonucleotide according to the invention corresponds to an siRNA capable of inhibiting the expression of the corresponding subunit of the CK2 protein kinase; the 17 to 21 nucleotide RNA sequence of the sense strand or positive strand is that of the target sequence of the transcript of the α, α' or β subunit of the mammalian CK2 protein kinase.

The invention encompasses the natural, synthetic, semi-synthetic or recombinant oligonucleotides targeting the CK2 protein kinase of any organism, in particular eukaryotic organism. Given the information provided with reference to the human and mouse sequences, those skilled in the art are in a position to find the equivalent positions in the sequences of other eukaryotic organisms, in particular of mammals, that are accessible in the sequence data bases.

In accordance with the invention, the identity of an oligonucleotide sequence with respect to a reference sequence is assessed as a function of the percentage of nucleotides that are identical, when the sequences are

aligned, so as to obtain the maximum correspondence between them.

According to an advantageous embodiment of said double-stranded oligonucleotide, said sequence is selected from the group consisting of:

a) a fragment of an α subunit defined by the RNA equivalent of the sequence SEQ ID Nos: 1 to 13,

b) a fragment of an α′ subunit defined by the RNA equivalent of the sequence SEQ ID Nos: 14 to 25,

c) a fragment of a β subunit defined by the RNA equivalent of the sequence SEQ ID Nos: 26 to 40, and

d) a sequence as defined in a), b) or c), truncated by one or two nucleotides at its 5′ and/or 3′ end.

For the purpose of the present invention, the expression "RNA equivalent of a DNA sequence" is intended to mean the sequence in which the deoxyribonucleotides (a, g, c, t) of said DNA sequence are replaced with the ribonucleotides (a, g, c, u).

According to another advantageous embodiment of said double-stranded oligonucleotide, each of the strands comprises a phosphate group in the 5′ position and a hydroxyl group in the 3′ position.

According to yet another advantageous embodiment of said double-stranded oligonucleotide, said protruding nucleotides of the 3′ ends are selected from the group consisting of the pairs tt and aa.

According to yet another advantageous embodiment of said double-stranded oligonucleotide, it is made up of two strands of 19 or 20 nucleotides.

According to an advantageous arrangement of this embodiment of said double-stranded oligonucleotide, it comprises a sense strand defined by the sequence SEQ ID No. 67 or 68.

According to yet another advantageous embodiment of said double-stranded oligonucleotide, it is made up of two stands of 21 to 23 nucleotides.

According to an advantageous arrangement of this embodiment of said double-stranded oligonucleotide, it comprises a sense strand as defined by the sequence SEQ ID Nos. 41 to 66, 69 to 81, 83 and 86.

Tables I, II and III below summarize the properties of the various oligonucleotides of sequences SEQ ID Nos. 1 to 86.

TABLE I: target sequences and SiRNA α

Name and No.	Mouse target sequence (sense sequence)	SiRNA	Size	Tm	%GC	Position/ATG codon NM_007787 mouse and NM_001895 of the human sequence	Hu*/mouse homology
CK2α1	*cagaccccgagagtactggga* (SEQ ID NO. 3)	gaccccgagaguacugggatt ttcuggggcucucaugacccu (SEQ ID No. 44)	21	61.5	57	54	2
CK2α2	aacacacacagaccccgagag (SEQ ID NO. 2)	aauacacacagaccucgagtt ttuuaugugugucuggagcuc (SEQ ID No. :43)	21	61.7	52.4	46	2
CK2α3	aagcagggccagagtttacac (SEQ ID NO:1)	gcagggccagaguuuacactt ttcgucccggucucaaaugug (SEQ ID No. 41)	21	58.6	52.4	18	0
CK2α4	aacacacacagaccccgagag (SEQ ID NO. 2)	cacacacagaccccgagagtt ttgugugugucuggggcucuc (SEQ ID No. :42)	21	59.3	52.4	46	2
CK2α5	aatttgagaggtgggcccaac (SEQ ID NO. 4)	uuugagaggugggcccaactt ttaaacucuccacccggguug (SEQ ID No. 45)	21	59.8	52.4	259	2
CK2α6	aatgtccgagttgcttctcga (SEQ ID NO. 5)	uguccgaguugcuucucgatt ttacaggcucaacgaagagcu (SEQ ID No. :46)	21	58.8	47.6	565	1
CK2α7	aacgatatcttgggcagacac (SEQ ID NO. 10)	cgauaucuugggcagacactt ttgcuauagaacccgucugug (SEQ ID No. 51)	21	57.9	47.6	808	1
CK2α8	aaaaccagcatcttgtcagcc (SEQ ID NO. 12)	aaccagcaccuugucagcctt ttuuggucguggaacgaucgg (SEQ ID No. 53)	21	60.3	47.6	863	2
CK2α9	aaccagcatcttgtcagccct (SEQ ID NO. 13)	ccagcaccuugucagcccutt ttggucguggaacagucggga (SEQ ID No. :54)	21	62.0	52.4	865	2
CK2α10	aggatagccaaggttctgg (SEQ ID NO. 9)	aggauagccaagguucuggtt ttuccuaucgguuccuugacc (SEQ ID No. .50)	21	58.9	47.6	730	0
CK2α11	tggtgaggatagccaaggttc (SEQ ID No. 8)	gugaggauagccaagguuctt ttcacuccuaucgguuccaag (SEQ ID No. :49)	21	57.1	47.6	725	0
CK2α12	tcagttggtgaggatagcca (SEQ ID No. 7)	caguuggugaggauagccatt ttgucaaccacuccuaucggu (SEQ ID No. 48)	21	58.8	47.6	720	0
CK2α13	gatatcttgggcagacactcc (SEQ ID No. 11)	uaucuugggcagacacucctt ttauagaacccgucugugagg (SEQ ID No. :52)	21	58.6	47.6	811	1
CK2α14	tgtggagcttgggttgtatgc (SEQ ID No. 6)	uggagcuuggguuguaugctt ttaccucgaacccaacauacg (SEQ ID No. 47)	21	61.8	47.8	644	1

* Hu = human

NB: the ATG is at position 1 of the mouse sequence No. NM_007787 and in position 277 of the human sequence No. NM_001895.

<u>TABLE II</u>: target sequences and SiRNA α'

Name	Human target sequence (sense sequence)	SiRNA	<u>SIZE</u>	Tm	%GC	Position	Hu/mouse homology
CK2α'1	aacagtctgaggagccgcgag (SEQ ID No. 14)	**cagccugaggagccgcgagtt** ttgucggacuccucggcgcuc (SEQ ID No. 55)	21	66.5	66.7	49	1 mismatch
CK2α'2	aaaacttggtcggggcaagta (SEQ ID No. 15)	**aacuuggucggggcaaguatt** ttuugaaccagccccguucau (SEQ ID No. ;56)	21	59.5	47.6	132	2 mismatches
CK2α'3	aaaggaccctgtgtcaaagac (SEQ ID No., 16)	**aggacccugugucaaagactt** ttuccugggacacaguuucug (SEQ ID No. 57)	21	62.4	47.6	306	1
CK2α'4	aagcaactctaccagatcctg (SEQ ID No. 17)	**gcaacucuaccagauccugtt** ttcguugagauggucuaggac (SEQ ID No. 58)	21	55.8	47 6	367	0
CK2α'5	aaagctctggattactgccac (SEQ ID No. 18)	**agcucuggauuacugccactt** ttucgagaccuaaugacggug (SEQ ID No. 59)	21	58.2	47 6	427	0
CK2α'6	aagggaatcatgcacagggat (SEQ ID No. 19)	**gggaaucaugcacagggautt** ttcccuuaguacgugucccua (SEQ ID No. 60)	21	62.8	47 6	451	0
CK2α'7	aagggaccagagctccttgtg (SEQ ID No. 20)	**gggaccagagcuccuugugtt** ttcccuggucucgaggaacuc (SEQ ID No. 61)	21	65.2	57.1	595	1
CK2α'8	aattgccaaggttctggggac (SEQ ID No. 21)	**uugccaagguucuggggactt** ttaacgguuccaagaccccug (SEQ ID No. 62)	21	61.5	52.4	735	2 but at the ends
CK2α'9	aacattcacggaagcgctggg (SEQ ID No. 22)	**cauucacggaagcgcugggtt** ttguaagugccuucgcgaccc (SEQ ID No. 63)	21	66.4	57.1	827	1
CK2α'10	aacaggcaccttgtcagcccg (SEQ ID No. 23)	**caggcaccuugucagcccgtt** ttguccguggaacagucgggc (SEQ ID No. 64)	21	61.0	61.9	868	2, of which one is the last nt
CK2α'11	aaagaggccatggagcaccc a (SEQ ID No. 24)	**agaggccauggagcacccatt** ttucuccgguaccucgugggu (SEQ ID No. 65)	21	68.4	57 1	949	0
CK2α'12	aaggagcagtcccagccttgt (SEQ ID No. 25)	**ggagcagucccagccuugutt** ttccucgucagggucggaaca (SEQ ID No. 66)	21	64.6	57 1	988	0

NB: The ATG is at position 99 of the mouse sequence No. NM_009974 and at position 164 of the human sequence No. NM_001896.

TABLE III: taget sequences and SiRNA β

Name	Human target sequence (sense sequence)	SiRNA	Size	Tm	%GC	Position	Hu/mouse homology
CK2β1	aagacaaccccaaccagagtg (SEQ IDNo. 32)	aagacaaccccaaccagagug ccuucuguugggguuggucuc (SEQ ID No. 73)	21	61.2	52.4	188	0 mismatch
CK2β2	tcaatgagcaggtccctcact (SEQ ID No. 27)	aaugagcagguccccucacu aguuacucguccagggagu (SEQ ID No. 68)	19	62	52.4	116	0
CK2β3	acctggagcctgatgaagaac (SEQ ID No. 29)	accuggagccugaugaagaac ccuggaccucggacuacuucu (SEQ ID No. 70)	21	60.5	52.4	164	1
CK2β4	tggagcctgatgaagaactgg (SEQ ID No. 30)	uggagccugaugaagaacugg ggaccucggacuacuucuuga (SEQ ID No. 71)	21	62.5	52.3	167	1
CK2β5	ggagcctgatgaagaactgga (SEQ ID No. 31)	ggagccugaugaagaacugga gaccucggacuacuucuugac (SEQ ID No. 72)	21	62.5	52.3	168	1
CK2β6	caatgagcaggtccctcacta (SEQ ID No. 28)	caaugagcaggucccucacua gaguuacucguccagggagug (SEQ ID No. 69)	21	60.1	52.3	117*	0
CK2β7	ccaagagacctgccaaccagt (SEQ ID No. 35)	ccaagagaccugccaaccagu cgguucucuggacgguuggu (SEQ ID No. 76)	21	62	47.6	527	1
CK2β8	cctgtcggacatcccaggtga (SEQ ID No. 33)	ccugucggacaucccagguga ccggacagccuguaggguccа (SEQ ID No. 74)	21	62.2	52.3	369	3
CK2β9	agcaacttcaagagcccagtc (SEQ ID No. 38)	agcaacuucaagagcccaguc ggucguugaaguucucggguc (SEQ ID No. 79)	21	60.8	52.3	613	0
CK2β10	ccaggctctacggtttcaaga (SEQ ID No. 36)	ccaggctctacggtttcaaga cggguccgagaugccaaaguu (SEQ ID No. 77)	21	60.5	52.3	554	1
CK2β11	agagcccagtcaagacgattc (SEQ ID No. 40)	agagcccagtcaagacgattc gttctcgggucaguucugcua (SEQ ID No. 81)	21	60.6	52.3	623	0
CK2β12	aacttcaagagcccagtcaag (SEQ ID No. 39)	aacttcaagagcccagtcaag gcuugaaguucucgggucagu (SEQ ID No. 80)	21	60.8	52.3	616	0
CK2β13	aagctctactgccccaagtgc (SEQ ID No. 34)	gcucuacugccccaagugctt ttcgagaugacgggguucacg (SEQ ID No. 75)	21	63	52.4	400	1
CK2β14	aagatccatccgatggcctac (SEQ ID No. 37)	gauccauccgauggccuactt ttcuagguaggcuaccggaug (SEQ ID No. 78)	21	62.3	42.9	571	2
CK2β15	aagactacatccaggacaat (SEQ ID No. 26)	gacuacauccaggacaautt ttcugauguagguccuguua (SEQ ID No. 67)	20	52.1	38.1	80	0
CK2β16	aagactacatccaggacaat (SEQ ID No. 26)	aagacuacauccaggacaatt ttuucugauguagguccuguu (SEQ ID No. 83)	21				
CK2β17	aagactacatccaggacaat (SEQ ID No. 26)	ugaagacuacauccaggacuu uuacuucugauguagguccug (SEQ ID No. 86)	21				

NB: The ATG is in position 341 of the human sequence No. NM_001320.

A subject of the present invention is also a single-stranded oligonucleotide, characterized in that it is

defined by the antisense strand or negative strand of the double-stranded oligonucleotide as defined above.

According to an advantageous embodiment of the double-stranded or single-stranded oligonucleotide as defined above, it is stabilized.

Stabilized oligonucleotides are known to those skilled in the art; they can be stabilized in particular by incorporation of modified bases during the *in vitro* synthesis or by modifications of the bases incorporated beforehand into said oligonucleotides. Examples of these modifications are given in Table IV.

A subject of the present invention is also a precursor of the double-stranded or single-stranded oligonucleotide as defined above, characterized in that it is selected from the group consisting of:

a) a single-stranded oligonucleotide corresponding to the sense or antisense strand as defined above,

b) a double-stranded oligodeoxynucleotide (DNA) corresponding to the sense and/or antisense strands of the double-stranded oligonucleotide as defined above,

c) a hairpin oligoribonucleotide comprising the sequences of the sense and antisense RNA strands as defined above, and

d) a double-stranded DNA made up of a sense strand corresponding to the DNA equivalent of the oligoribonucleotide defined in c) and of an antisense strand complementary thereto.

For the purpose of the present invention, the expression "DNA equivalent of an RNA sequence" is intended to mean the sequence in which the

ribonucleotides (a, g, c, u) of said RNA sequence are replaced with deoxyribonucleotides (a, g, c, t).

The precursors are useful for producing the single-stranded and double-stranded oligonucleotides according to the present invention by the conventional techniques of oligonucleotide synthesis and of transcription using a recombinant vector.

Each of the strands of the siRNA can be synthesized separately and then the complementary strands are hybridized so as to form RNA duplexes. Alternatively, the strands of the siRNA can be synthesized simultaneously.

The siRNA can also be produced in the form of a hairpin RNA molecule according to the principle described in Brummelkamp et al., Science, 2002, **296**, 550-553. The hairpin RNA molecule is subsequently cleaved in the cells transfected with said RNA molecule or transduced with an appropriate transcription vector, so as to release the siRNA. This hairpin RNA molecule comprises the sequences of the two strands of the siRNA separated by a short sequence of noncomplementary oligo-ribonucleotides of approximately 3 to 12 nucleotides forming a loop of approximately 5 to 15 nucleotides. For example, a loop of approximately 10 nucleotides is formed from a short sequence of approximately 8 ribonucleotides and of two nucleotides derived from the 3′ end of the sense strand of the siRNA.

The single-stranded and double-stranded oligo-nucleotides according to the present invention can be either produced by chemical synthesis or by transcription *in vitro* (test tube) or in cell culture, and then administered *in vivo*, or they are produced *in vivo* in the cells of an organism which have been modified with a transcription vector (gene therapy) or a DNA encoding said siRNAs (transgenesis).

The chemical synthesis is carried out according to the conventional phosphoramidite method described in Elbashir et al., Nature, 2001, 411, 494-498. For example, each of the strands of the siRNA can be synthesized according to β-cyanoethyl phosphoramidite chemistry on a solid support using 2′-*O-tert*-butyl-dimethylsilyl (TBDMS) as a group for protecting the 2′-position of the ribonucleotide. Other protective groups can be used; silyl ether, which protects the 5′-hydroxyl end of the ribonucleotide, can be used in combination with a labile orthoester which protects the 2′-hydroxyl of the ribonucleotide.

The transcription by means of a recombinant vector uses a double-stranded DNA encoding for at least one or the two strands of the siRNA or else a hairpin RNA as defined above. Such DNAs cloned into appropriate expression vectors allow separate or simultaneous transcription of the two complementary strands of said siRNA, as described, respectively, in Sadher et al., Biochem. Int., 1987: 14, 1015 and in European patent EP 0618 966 in the name of Cis Bio International. For example, the method of preparing double-stranded RNA described in European patent EP 0618 966 uses a DNA template attached to a support which allows the simultaneous transcription of the two RNA strands in the form of double-stranded RNA after a step consisting of amplification (PCR) of the target DNA sequence. The double-stranded RNA obtained can be attached to a support and several different siRNA sequences can be analyzed simultaneously.

A subject of the invention is also an expression cassette, characterized in that it comprises at least one precursor as defined above, under the control of appropriate transcriptional regulatory elements, in particular an inducible or noninducible promoter and a transcription terminator.

A subject of the invention is also a eukaryotic or prokaryotic vector comprising an insert consisting of an oligonucleotide as defined above; preferably, said vector is an expression vector into which an expression cassette as defined above is inserted.

These vectors are constructed and introduced into host cells by conventional recombinant DNA and gene therapy methods, which are known in themselves. Many vectors into which a nucleic acid molecule of interest can be inserted in order to introduce it into and to maintain it in a eukaryotic or prokaryotic host cell are known in themselves; the choice of an appropriate vector depends on the use envisioned for this vector (for example, replication of the sequence of interest, expression of this sequence, maintaining the sequence in extrachromosomal form or else integration into the host's chromosomal material), and also on the nature of the host cell. Use may be made, inter alia, of viral vectors such as adenoviruses, retroviruses, lentiviruses and AAVs into which the sequence of interest has been inserted beforehand, or else nonviral vectors such as plasmids.

Preferably, said vector is a DNA vector (recombinant plasmid or virus) comprising a double-stranded oligodeoxynucleotide as defined above; such a vector encoding an siRNA as defined above is useful for the *in vitro* or *in vivo* production of said siRNAs.

Vectors that are particularly suitable for the stable expression of siRNAs are in particular those described in T.R. Brummelkamp et al., Science, 2002, **296**, 550-553.

A subject of the present invention is also eukaryotic or prokaryotic cells modified with an oligonucleotide,

a precursor, an expression cassette or a vector as defined above.

A subject of the present invention is also a transgenic nonhuman animal, characterized in that it comprises cells modified with an oligonucleotide, a precursor, an expression cassette or a vector as defined above.

A subject of the present invention is also a pharmaceutical composition, characterized in that it comprises at least one oligonucleotide, one precursor or one vector encoding said siRNA, as defined above, and a pharmaceutically acceptable carrier.

Said oligonucleotides (double-stranded oligonucleotide (siRNA), or single-stranded oligonucleotide or precursor of the above), isolated or inserted into a vector as defined above, are introduced into target cells either by passive diffusion, or using physical methods such as electroporation or microinjection, or by associating them with any substance(s) that make(s) it possible to cross the plasma membrane, such as transporters, for instance nanotransporters, liposomes, lipids or cationic polymers, such as calcium phosphate (Sigma kit ref. CA-PHOS), amine (Ambion kit ref. 4502), lipofectamine (Polyplus-transfection kit, ref. 101-05) or fugene-6 (Roche, ref. 1815-091). In addition, these methods can advantageously be combined, for example using electroporation combined with liposomes.

In certain cases, it is not necessary to associate the oligonucleotides according to the invention with a substance allowing them to pass through the plasma membrane, insofar as the siRNAs are small enough to diffuse freely in the various cell compartments. They can act in the cytoplasm, but also at the nuclear membrane, or even in the nucleus.

According to an advantageous embodiment of said composition, said oligonucleotide, said precursor or said vector are associated with at least one substance that makes it possible to cross the plasma membrane, such as transporters, for instance nanotransporters, liposomes, lipids or cationic polymers.

According to another advantageous embodiment of said composition, said oligonucleotide, said precursor or said vector is associated with at least one substance that allows targeting into specific cells, tissues or organs, such as antibodies and peptides, in particular peptides capable of crossing the blood-brain barrier, for instance the Pep:Trans™ peptides (http://www.syntem.com/english/techpeptrans.html). Other peptides can advantageously be used to facilitate the transfection of siRNA through the plasma membrane of cells; the antibodies described in Lu Z.R. et al. (Nature Biotechnol., 1999, 17, 1101-1104) can in particular be used for targeting cancer cells.

According to yet another advantageous embodiment of said composition, said oligonucleotide, said precursor or said vector is combined with at least one antiviral or anticancer agent.

According to another advantageous embodiment of said composition, it comprises a mixture of several oligonucleotides or of their precursors, or else one or more expression vectors for said mixture of oligonucleotides, and in particular a mixture comprising at least one oligonucleotide specific for the α subunit, at least one oligonucleotide specific for the α' subunit and at least one oligonucleotide specific for the β subunit.

A subject of the present invention is also the use of an oligonucleotide, of a precursor or of a vector as

defined above, for preparing a medicinal product for use in the prevention and/or treatment of cancer.

A subject of the present invention is also the use of a oligonucleotide, of a precursor or of a vector as defined above, for preparing a medicinal product for use in the prevention and/or treatment of viral diseases.

A subject of the present invention is also a product containing at least one oligonucleotide, one precursor or one vector as defined above and an anticancer active ingredient, as a combined preparation for simultaneous, separate or sequential use, in the prevention and/or treatment of cancer.

A subject of the present invention is also a product containing at least one oligonucleotide, one precursor or one vector as defined above and an antiviral active ingredient, as a combined preparation for simultaneous, separate or sequential use, in the prevention and/or treatment of viral diseases.

The useful dosage varies according to the condition to be treated, to the route and rate of administration, and to the nature and the weight of the species to be treated (human or animal). The oligonucleotides are used by digestive (oral, sublingual), parenteral or local administration. They may be in the form of simple or sugar-coated tablets, of gelatine capsules, of granules, of a syrup, of suppositories, of injectable preparations, of ointments, of creams, of gels or of an aerosol, which are prepared according to the usual methods. In these pharmaceutical forms, the oligonucleotides are incorporated into excipients normally used in pharmaceutical compositions, such as talc, gum arabic, lactose, starch, magnesium stearate, cocoa butter, aqueous or nonaqueous carriers, fatty substances of animal or plant origin, paraffin

derivatives, glycols, various wetting, dispersing or emulsifying agents, or preserving agents.

In vitro, the concentrations that can be used in rats are between 10 nM and 200 µM; the *in vivo* doses can therefore be between 1 µg and 20 mg/kg. The corresponding doses in humans can be deduced from this information.

A subject of the invention is also the use of an oligonucleotide, of a precursor, of a vector, of modified eukaryotic or prokaryotic cells or of a transgenic animal, as defined above, for screening for molecules capable of selectively modulating the activity of the α, α′ or β subunits of the CK2 protein; for example, it is possible to specifically inhibit the expression of one of the subunits *in vivo* or *in vitro* and thus to screen for molecules that are active on the other subunit; such molecules represent potential medicinal products that are useful for the prevention and treatment of pathologies related to a deregulation (increase or decrease) in the activity of the CK2 protein kinase in cells.

By way of example of a pathology related to a deregulation of CK2 activity, mention may be made of male infertility due to an absence of CK2 α′ with no compensation by α which is absent in the germ cells at the final stage of spermatogonia differentiation (Xu et al., Nature Gen., 1999, 23, 118-121).

Compared with the antisense oligonucleotides of the prior art, the oligonucleotides, and in particular the siRNAs, according to the invention have the following advantages:

- they are stable *in vitro* and *in vivo*,

- they are active at low concentrations (of the order of 20 nM *in vitro*) and inhibit very effectively (> 80% inhibition) the expression and, consequently, the activity of the CK2 protein kinase in cells,

- they have a prolonged effect, up to 6 days.

Besides the above arrangements, the invention also comprises other arrangements which will emerge from the description which follows, which refers to examples of use of the siRNA corresponding to the sequence SEQ ID No. 26 according to the present invention and also to the attached drawings in which:

- figure 1 illustrates the immunofluorescence analysis of the inhibition of the expression of the CK2 protein kinase β subunit by an siRNA targeting the sequence SEQ ID No. 26 (βsi); the cells are labeled with an anti-CK2β primary antibody and a fluorescein-coupled secondary antibody (green fluorescence), and then counter stained with propidium iodide (red fluorescence). The inhibition is measured by the ratio of the number of CK2β-positive cells (green fluorescence) to the total number of cells (red fluorescence). The values represent the means of two independent measurements ± SEM. A final concentration of 100 nM of siRNA inhibits 90% of the expression of the CK2 protein kinase β subunit;

- figure 2 illustrates the kinetics of inhibition of the expression of the CK2 protein kinase β subunit in the presence of a synthetic siRNA (siRNA-β) targeting the sequence SEQ ID No. 26;

- figure 3 illustrates the comparative analysis of the inhibition of the expression of the CK2 protein kinase β subunit by a synthetic siRNA CK2β (sense sequence SEQ ID No. 83 and antisense sequence SEQ ID No. 84) or an siRNA CK2β expressed in the target cells

by means of a recombinant vector (pSUPERsiRNA) producing a hairpin RNA (SEQ ID No. 85) corresponding to the siRNA of sense sequence SEQ ID No. 86 and antisense sequence SEQ ID No. 87;

- figure 4 illustrates the improvement in the siRNA sequences. Human cells (MCF7 line) and murine cells (NIH 3T3 line) were transfected with various siRNAs targeting the α subunit (CK2α3, CK2α7, CK2α5) and possibly exhibiting mismatches with the target RNA, and a control siRNA (ctrl). The cells were labeled with an anti-CK2α primary antibody and a fluorescein-coupled secondary antibody (green fluorescence), then counter stained with propidium iodide (red fluorescence). The inhibition of the expression of the α subunit is measured by the ratio of the number of CK2α-positive cells (green fluorescence) to the total number of cells (red fluorescence).

<u>EXAMPLE 1</u>: Expression of an oligoribonucleotide according to the invention in target cells modified with a recombinant vector

a) A DNA sequence (gatcccctgaagactacatccaggacttcaagag agtcctggatgtagtcttcattttggaaa, SEQ ID No. 82) was cloned into the vector pSUPER according to the conditions described in Brummelkamp TR et al. (Science, 2002, **296**, 5567, 550-3). The recombinant vector thus obtained (pSUPER siRNA) allows the expression of an siRNA-β or CK2β targeting the sequence SEQ ID No. 26, from a hairpin transcript (figure 3).

b) NIH 3T3 cells are transfected with the vectors obtained in a) according to a transfection protocol using Fugene 6 (Roche).

<u>EXAMPLE 2</u>: Preparation of synthetic ologoribonucleotides that are optionally stabilized

a) The two RNA strands are synthesized according to known methods (RNA phosphoramidine method, see in particular Elbashir S.M. et al., Nature, 2001, 411, 494-498).

b) In order to stabilize them, it is advantageous to modify them by inserting modified nucleotides into the two RNA strands, during the *in vitro* synthesis.

Table IV below illustrates examples of modified nucleotides.

Modified nucleotide	First application	Second application
2' F-CTP	Resistance to nuclease	
2'F-UTP	Resistance to nuclease	
2'NH_2-CTP	Resistance to nuclease	
2'NH_2-UTP	Resistance to nuclease	
2'N_3-CTP	Resistance to nuclease	Post-synthesis modification
2'N_3-UTP	Resistance to nuclease	Post-synthesis modification
2-thio CTP	UV-crosslinking	
2-thio UTP	Modified hybridization	UV-crosslinking
4-thio UTP	Modified hybridization	UV-crosslinking
5-iodo CTP	UV-crosslinking	
5-iodo UTP	UV-crosslinking	
5-bromo UTP	UV-crosslinking	
2-chloro ATP	UV-crosslinking	
Adenosine 5'-(1-thiotriphosphate)	Chemically unstable	Resistance to nuclease
Cytidine 5'-(1-thiotriphosphate)	Chemically unstable	Resistance to nuclease
Guanosine-5'-(1-thiotriphosphate)	Chemically unstable	Resistance to nuclease
Uridine-5'-(1-thiotriphosphate)	Chemically unstable	Resistance to nuclease
Pseudo-UTP		
5-(3-aminoallyl)-UTP	Post-synthesis modification	
5-(3-aminoallyl)-dUTP	Post-synthesis modification	

Such nucleotides are in particular available from Ambion (http://www.ambion.com).

EXAMPLE 3: Inhibition of the expression of the CK2 protein kinase β subunit by synthetic siRNA

3T3 fibroblasts were cultured in a drop of 5 µl (2000 cells) in complete culture medium, in the wells of an

immunofluorescence slide (40 wells 2 mm in diameter; super teflon slide, reference 74890.01 (Prolabo)). The 3T3 cells were transfected using the siPort® transfection kit (Ambion), with a final concentration of 5, 20, 50 or 100 nM of siRNA targeting the sequence SEQ ID No. 26, in a volume of 5 µl, or were nontransfected, and then the cells were incubated for 2 days at 37°C. The cells were subsequently washed and fixed with a paraformaldehyde solution (4% in PBS). The cells were subsequently stained with propidium iodide and labeled using a primary antibody against the CK2 protein β subunit (βc antibodies; Filhol et al. 1994 Biochem Biophys Res Commun. 198 660-5) and a secondary antibody coupled to a fluorophor, such as cyanamide 3. The fluorescence was analyzed using a scanner (Genomic Solution) and the inhibition of expression of the CK2 protein kinase was expressed by the ratio of the number of cells expressing the CK2 protein kinase (red cells labeled with the βc antibodies) to the total number of cells (blue cells labeled with propidium iodide).

The results are given in figure 1 and show that a concentration of 20 nM of siRNA inhibits 90% of the expression of the CK2 protein kinase β subunit.

<u>EXAMPLE 4</u>: Study of the inhibition of the expression of β CK2 by synthetic siRNA or an siRNA produced in the target cells modified with an expression vector

NIH 3T3 cells transfected either with an siRNA-β targeting the sequence SEQ ID No. 26 (20 nM) or with the corresponding expression vector (pSUPER siRNA) are cultured for the periods indicated in figure 2. After washing in PBS, they are lysed in a TDG buffer (10 mM Tris, HCl, pH 7.4, 0.1% glycerol, 1 mM DTT, 500 mM NaCl, 0.1% Triton X-100) and centrifuged for 15 min at 15 000 g at 4°C. The supernatant is assayed for its protein content and 40 µg are analyzed by SDS-PAGE. The proteins are then transferred onto a PVDF membrane.

After saturation of the membrane in PBS containing 0.05% Tween 20 and 3% BSA for 1 hour, the CK2β subunit is visualized with the βC antibody.

An inhibition of the expression of the CK2 protein β subunit is observed with the synthetic siRNA or the siRNA produced by an expression vector (figure 3); this inhibition is observed from 24h, as shown by the inhibition kinetics with the synthetic siRNA (figures 2 and 3).

<u>EXAMPLE 5</u>: Improvement in the siRNA sequences

The inhibition of the expression of the human or murine CK2 protein α subunit by various siRNAs (CK2α3, CK2α7, CK2α5) exhibiting or not exhibiting mismatches with the target RNA was analyzed by immunofluorescence as described in example 3. The siRNAs are specific for the murine transcript and exhibit 0 (CK2α3), 1 (CK2α7) or 2 (CK2α5) mismatch(es) with the human transcript (Table I); for α7, the mismatch is in the 5′ portion of the target sequence, whereas, for α5, the mismatch is in the 3′ portion of the target sequence.

Human cells (MCF7 line) and murine cells (NIH 3T3 line) were transfected with various siRNAs targeting the α subunit (CK2α3, CK2α7, CK2α5) or with a control siRNA (ctrl). The cells were labeled with an anti-CK2α primary antibody and a fluorescein-coupled secondary antibody (green fluorescence), and then counter stained with propidium iodide (red fluorescence). The inhibition of the expression of the α subunit was measured by the ratio of the number of CK2α-positive cells (green fluorescence) to the total number of cells (red fluorescence).

The results show that the presence of any mismatch with the target RNA decreases the effectiveness of the

siRNAs (figure 4; see α5 in the human line compared with the murine line).

As emerges from the above, the invention is in no way limited to those of its methods of implementation, execution and application which have just been described more explicitly; on the contrary, it encompasses all the variants thereof that may occur to those skilled in the art, without departing from the context or the scope of the present invention.